

Characterization of Seismoacoustic Properties of Marine Sediments

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LONG-TERM GOALS

Several fundamental controversial problems are still unresolved regarding the seismoacoustic properties of saturated sand [1-3], moist sand [4-5], and dry beach sand [4-5]. The long-term goal of the research is to develop fundamental physical understanding of mechanisms affecting the seismoacoustic properties of unconsolidated marine sediments under various conditions. The research outcome would lead to accurate modeling of marine sediments and reliable seismoacoustic detection of buried objects.

OBJECTIVES

Investigate grain to grain seismoacoustic coupling mechanisms of compacted sand affected by water content, salt, grain shape, grain size, roughness, compactness, microbubbles, capillarity, and heterogeneous nucleation at grain interfaces.

APPROACH

Study some aspects of compressed sand grain to grain coupling by focusing on basic solid/liquid/solid shear coupling mechanisms with a confined ultrathin water layer. Use ultrasonic modeling techniques developed by the author since 1979 [6-12] to obtain qualitative and quantitative experimental results under controlled laboratory conditions to identify, isolate, and characterize different seismoacoustic coupling mechanisms. Conduct experiments on sand, spherical glass beads, and glass plates. A broadband ultrasonic pulse is transmitted in the models, and the received signal is analyzed to provide the desired acoustic properties. Enhanced ultrasonic modeling is used as needed to increase the signal level of a specific mechanism under study.

WORK COMPLETED

The work started in July 2002 nine months after the beginning of Fiscal Year 2002 delayed by funding. Under the previous ONR contract N0001400C0386, preliminary results were obtained from glass plates revealing the potential existence of a "suction-cup" effect between sand grains strongly coupling shear waves in the absence of roughness [6]. The conventional treatment of elastic wave propagation dictates that shear waves are not transmitted through a water layer between two solid walls. The seemingly simple suction-cup effect problem is in fact a complex problem as the water layer thickness is decreased. Substantial progress has been made during this three months work period identifying mechanisms related to the adhesion of two solids with an ultrathin liquid layer.

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14. ABSTRACT <p>Several fundamental controversial problems are still unresolved regarding the seismoacoustic properties of saturated sand [1-3], moist sand [4-5], and dry beach sand [4-5]. The long-term goal of the research is to develop fundamental physical understanding of mechanisms affecting the seismoacoustic properties of unconsolidated marine sediments under various conditions. The research outcome would lead to accurate modeling of marine sediments and reliable seismoacoustic detection of buried objects.</p>				
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In partially saturated sand, capillary forces are present. The thin water film existing between sand grains has a dramatic effect on the acoustic properties of sand. The Laplace-Young equation of capillarity [13], used to predict the meniscus forces assumes the surface tension to be a constant. It is not known if the Laplace-Young equation is valid for a confined ultrathin water film as the capillary forces exceed the tensile strength of the water in the presence of heterogeneous nucleation.

The interfacial viscous force described by Stefan's equation [14] is based on a viscosity that is independent of the layer thickness. Van der Veen et al. [15] showed that when an ultrathin liquid film is confined in nanometer gaps between two solid surfaces, the liquid molecules become ordered giving rise to solid-like properties and causes the surfaces to stick. An additional complication arises when dynamic shear waves are introduced. Archer et al. [16] showed that a liquid can fracture like a solid forming a vacuum cavity above some critical shearing rate. One point of interest is the instability of a confined ultrathin water layer in the presence of heterogeneous nucleation and cavitation in tension and shear. Microbubbles in seawater dissolve because the pressure inside the bubble is greater than the pressure in the water. The behavior of a shearing cavitation bubble confined between two plates in a microchannel is not known. Microbubbles trapped in ultrathin capillary channels cannot be removed by suction because the pressure exerted by capillary forces can far exceed one atmosphere. Gay and Leibler [17] described the role of the suction-cup effect in the theory of tackiness of adhesive polymer films increasing the bonding strength by up to 10,000 times. Later work by Creton et al [18] indicated that the suction cup effect contributes only a very small part to the energy of debonding due to the very peculiar properties of deformability of the adhesives. There are several mechanisms responsible for increasing the shear modulus of sand. Losert et al. [19] reported on gradual slow strengthening of wet sand under low pressure.

Work is in progress on shear wave coupling between glass plates sticking with a ruptured ultrathin water layer. The studies include time dependent behavior, cavitation in shear, salt crystallization, normal and shear forces required to separate the shear coupled glass plates, surface roughness, multiple parallel plates, irreversible bonding as function of applied load, and compressional waves in saturated glass beads.

RESULTS

New preliminary ultrasonic experiments were conducted on glass models (microscope slides) to plan the work (Fig. 1-4). Shear waves were transmitted and detected across two glass plates using identical piezoelectric transducers as shown in Fig. 1. A Plexiglas block (2.2 cm thick) was epoxied between each transducer and plate to introduce a time delay to separate the detected shear wave from the compressional wave. The waveforms of the received signals were recorded with different plate contact conditions as described in the figure captions.

In one experiment, a drop of distilled water was placed between two clean glass microscope slides pressed against each other with a slipping motion. The glass plates strongly adhered and Newton interference fringe patterns were observed. The trapped thin water layer between the plates ruptured with shear cavitation and tiny elongated bubbles formed. The interference fringe pattern is displayed in Fig. 2. Strong shear wave coupling was observed *without* the use of an external load squeezing the plates. By immersing the plates, sliding contact conditions resulted and the shear wave disappeared. A shear wave was detected when a 35 kg load was applied to the wet sliding contact. The shear wave vanished when the 35 kg load was removed (Fig. 2).

The results were very different when a 100 kg load was applied as shown in Fig. 3. The plates remained bonded after removing the 100 kg load. The shear wave detected one hour after removing the 100 kg load is displayed in the second trace in Fig. 3. Again, the shear wave disappeared when the plates were immersed in water without the load. A minimum loading force F_{\min} had to be surpassed to reach irreversible adhesion between the wet glass plates.

Results from a 6 months old two-glass plates model with seawater are presented in Fig. 4. A photograph of the interference fringe pattern is shown. The plates were bonded together with several mechanisms including capillary forces and salt crystallization. Strong shear wave coupling was observed. It appears that a ruptured ultrathin trapped seawater layer was preserved for 6 months between the plates. The plates remained bonded when immersed in water indicating possible formation of a seal from the crystallized salt. A blade edge was used to forcefully separate the two plates. This experiment raised interesting questions about time-dependent behavior of trapped ruptured ultrathin seawater layer.

Other preliminary experiments were carried out to determine the force needed to separate the plates both in shear and in tension while monitoring the transmission of shear waves. The normal force used to separate two optically flat glass blocks bonded with a ruptured ultrathin distilled water layer was about 11% greater than the atmospheric suction-cup effect. The problem is still being investigated.

IMPACT/APPLICATIONS

Develop fundamental physical understanding of mechanisms controlling the seismoacoustic properties of marine sediments leading to accurate acoustic modeling of littoral surficial layer and reliable detection of buried objects in shallow water and on the beach.

TRANSITIONS

The research outcome would contribute to developing basic physical understanding important for generating valid theoretical models to predict the acoustic properties and seismoacoustic response of sandy marine sediments for reliable high resolution detection of buried objects in saturated and moist beach sand.

RELATED PROJECTS

The work relates to several DOD sponsored research projects on marine sediment modeling, high-frequency sound interaction, seismic sonar, surfseisms, and air bubbles in sediments (N. P. Chotiros, R. D. Stoll, E. I. Thorsos, D. R. Jackson, A. N. Ivakin, K. Williams, H. Simpson, M. Richardson, R. Stoll, M. Buckingham, T. Muir, E. Smith, G. D'Spain, D. Velea, J. M. Sabatier, G. B. Deane, R. A. Stephen, and P. Kackzkowski). A portion of the effort will deal with measuring the compressional waves in water-saturated glass beads complementing the research by Prof. Michael Buckingham at Scripps Institution of Oceanography on modeling wave propagation in unconsolidated marine sediments.

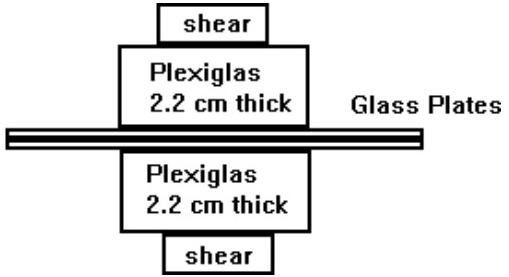


Fig. 1. Generation and detection of shear waves in two parallel glass plate models with an ultrathin water capillary layer. Plexiglas block used between shear wave transducer and glass plate to introduce a time delay to separate the detected shear waves from the compressional wave.

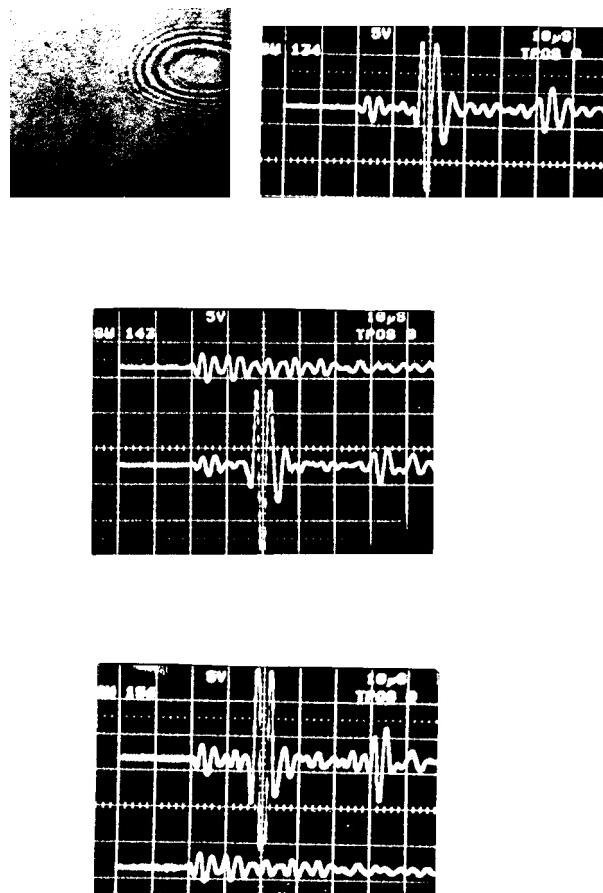


Fig. 2. Detected waveforms from two glass plates model under various conditions. Top: Substantial shear wave coupled between two smooth glass plates (microscope slides) bonded with a ruptured ultrathin capillary water film with no external load. Newton interference fringes displayed. Middle: No shear wave detected for sliding contact with plates immersed in water (second trace). Shear wave detected for dry contact condition with a 35 kg load (third trace). Bottom: Wet contact with a 35 kg load (fourth trace). Removing the 35 kg load restored the sliding contact and the shear wave disappeared (fifth trace). Compare with the 100 kg case shown in Fig. 3.

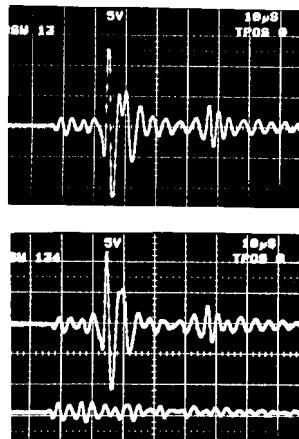


Fig. 3. Two glass plates remained bonded after removing a 100 kg load cycled four times (load /no load). Substantial shear wave detected after removing the load as shown in top trace. After waiting one hour, the shear wave amplitude decreased slightly (middle trace). The shear wave disappeared when the glass plates were immersed in water (bottom trace).

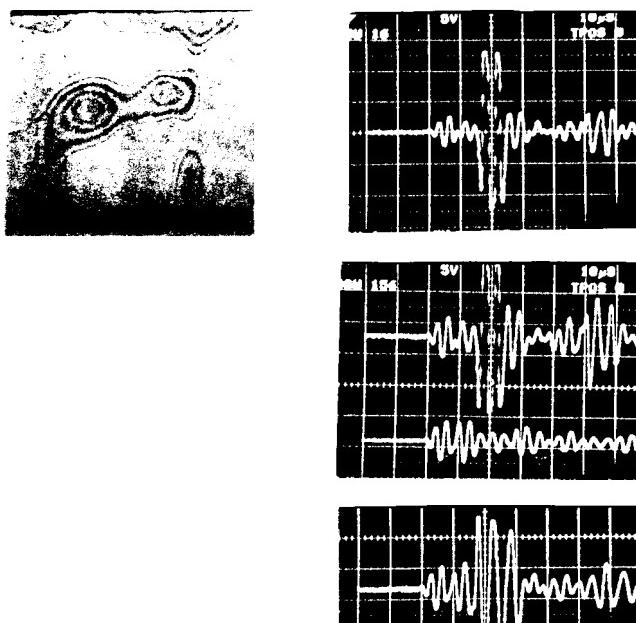


Fig. 4. Top: Interference fringes from an ultrathin ruptured seawater film trapped between two glass plates for a period of 6 months. A substantial shear wave was detected with the plates bonded together with several mechanisms including capillary forces and salt crystallization as shown in the first trace (no external load applied to hold the plates together). The plates remained bonded when immersed in water indicating possible formation of a seal from the crystallized salt (second trace). Used a blade edge to force the separation of the immersed plates and create a sliding contact (third trace). A 15 kg load was added to couple a noticeable shear wave.

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